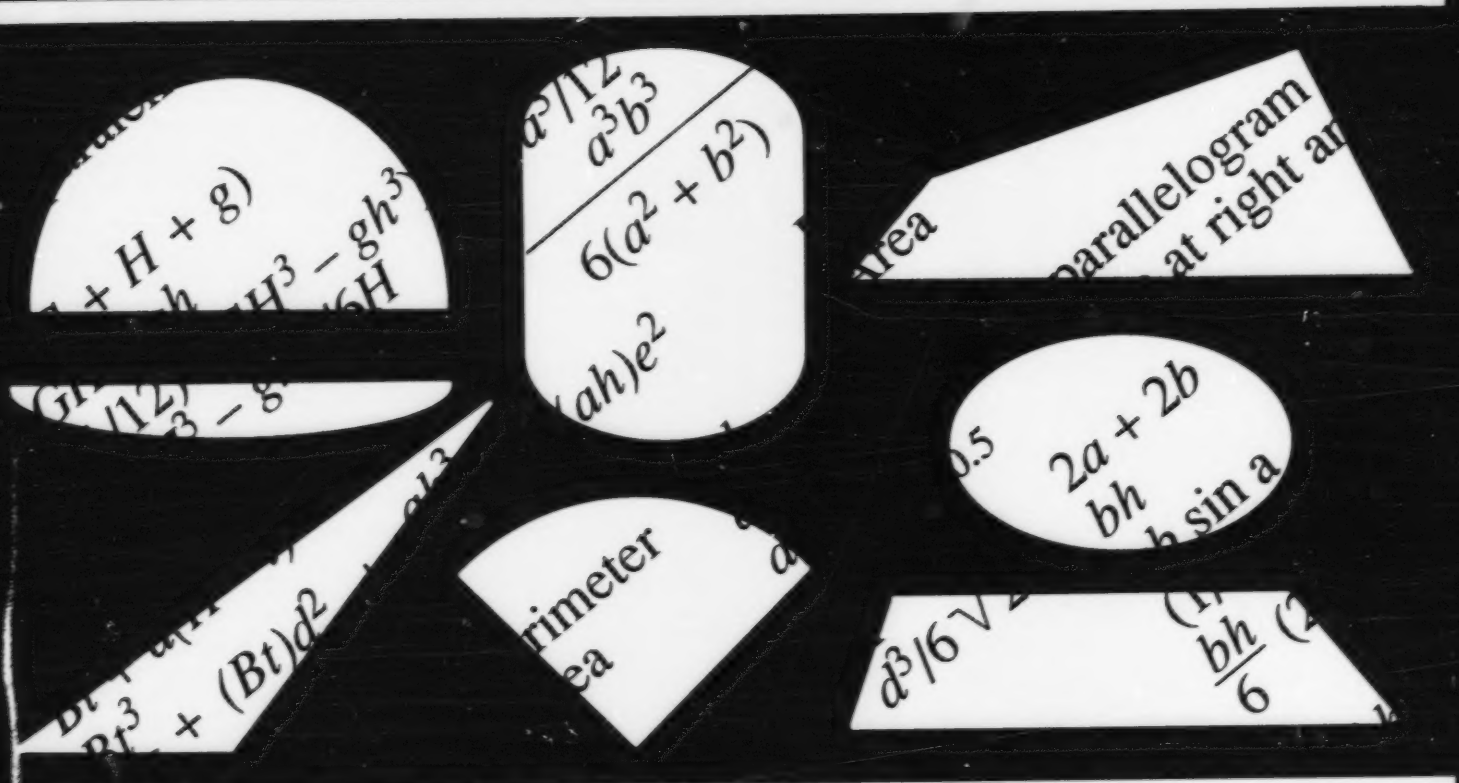
Agriculture Canada

Handling Agricultural Materials

Engineering Data



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FOREWORD

Handling Agricultural Materials is produced in several parts as a guide to designers of materials-handling systems for farm and associated industries. Sections deal with selection and design of specific types of equipment for materials handling and processing. Items may be required to function independently or as components of a system. The design of a complete system may require information from several sections of the manual.

This section was prepared by UMA Engineering Ltd., Winnipeg, Man., for the Canada Committee on Agricultural Engineering Services of the Canadian Agricultural Services Coordinating Committee.

1 INTRODUCTION

This volume presents a compendium of useful formulas, conversion factors, and charts. The conversion factors offer a guide to the International System (SI) of Units. The equations, properties of shapes and volumes, and the psychrometric charts are included since almost all design requirements for systems that handle agricultural materials depend on them.

The information in this volume relates to various sections of the series of manuals *Handling Agricultural Materials*, and should help users of the manuals better understand them. The engineering data have been consolidated in a single volume this way to avoid duplication and repetition throughout the series.

A thorough reading of this section is not necessary before reading or applying the information from other sections. Use this one instead as a reference guide, reviewing the contents to better understand the information provided in other volumes in the series.

Although the contents of this volume may appear very simple and elementary to many readers, it will be relatively new to others. Users of the series *Handling Agricultural Materials* range from students to experienced designers working in a variety of disciplines. Their common goal, however, is to select and design specific equipment for material handling and processing in agricultural applications.

2 USEFUL FORMULAS

2.1 General equations

2.2 *Factors and expansions*

$$(a \pm b)^2 = a^2 \pm 2ab + b^2$$

$$(a \pm b)^3 = a^3 \pm 3a^2b + 3ab^2 \pm b^3$$

$$a^2 - b^2 = (a - b)(a + b)$$

$$a^3 - b^3 = (a - b)(a^2 + ab + b^2)$$

$$a^3 + b^3 = (a + b)(a^2 - ab + b^2)$$

2.3 *Powers and roots*

$$(a)^x (a)^y = a^{(x+y)}$$

$$(a)^x / (a)^y = a^{(x-y)}$$

$$(a^x)^y = a^{xy}$$

$$a^{-x} = 1/a^x$$

$$(ab)^x = a^x b^x$$

2.4 *Proportion*

If $\frac{a}{b} = \frac{c}{d}$

then $\frac{a+b}{b} = \frac{c+d}{d}$

$$\frac{a-b}{b} = \frac{c-d}{d}$$

$$\frac{a-b}{a+b} = \frac{c-d}{c+d}$$

2.5 Quadratic equation

For $ax^2 + bx + c = 0$

$$x = \frac{-b \pm (b^2 - 4ac)^{0.5}}{2a}$$

Assuming a, b, and c are real, then:

- the roots are real and unequal if $b^2 - 4ac$ is positive
- the roots are real and equal if $b^2 - 4ac$ is zero
- the roots are imaginary and unequal if $b^2 - 4ac$ is negative

2.6 Velocity, acceleration, distance, and time

For objects accelerating uniformly, use the following relationships to calculate linear or angular acceleration.

2.7 *Linear motion*

$$L = 1/2(V_1 + V_2)t$$

$$a = (V_2 - V_1)/t$$

$$L = V_1 t + 1/2\, at^2$$

$$V_2^2 = V_1^2 + 2a\, L$$

where L = linear displacement (m)

V_1 = initial linear velocity (m/s)

V_2 = final linear velocity (m/s)

t = time

a = linear acceleration (m/s^2)

2.8 *Angular acceleration*

$$\beta = 1/2(\omega_1 + \omega_2)t$$

$$\alpha = (\omega_2 - \omega_1)/t$$

$$\beta = \omega_1 t + 1/2\alpha t^2$$

$$\omega_2^2 = \omega_1^2 + 2\alpha\beta$$

where β = angular displacement (rad)

ω_1 = initial angular velocity (rad/s)

ω_2 = final angular velocity (rad/s)

t = time (s)

α = angular acceleration (rad/s^2)

2.9 Trigonometry

Refer to Fig. 1.

$$\sin \Sigma = y/r$$

$$\cos \Sigma = x/r$$

$$\tan \Sigma = y/x$$

$$\csc \Sigma = r/y$$

$$\sec \Sigma = r/x$$

$$\cot \Sigma = x/y$$

where $\sin \Sigma$ = sine Σ

$\cos \Sigma$ = cosine Σ

$\tan \Sigma$ = tangent Σ

$\csc \Sigma$ = cosecant Σ

$\sec \Sigma$ = secant Σ

$\cot \Sigma$ = cotangent Σ

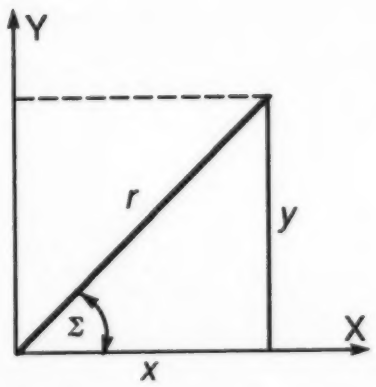


Fig. 1. Basic trigonometry.

2.10 Miscellaneous constants

The following physical constants are considered basic and necessary. They are used throughout the series *Handling Agricultural Materials*.

- Acceleration due to gravity at sea level = 9.80665 m/s^2
- Velocity of sound in dry air at 0°C = 331.36 m/s
- Velocity of light in vacuum = 2.998×10^8 m/s
- Heat of fusion of water at 0°C = 331.5 J/g
- Heat of vaporization of water at 100°C = 2257.5 J/g

2.11 Mechanical parameters

The following equations are commonly used to determine the mechanical specifications for equipment handling agricultural materials.

2.12 *Power* Power refers to the capacity of a machine to do work. In mechanical terms, work indicates a force moving through a distance.

$$\text{Linear power (W)} = F \times L/t = F \times V$$

where F = force (N)

L = distance (m)

t = time (s)

V = velocity (m/s)

In calculating rotary power, note that a force acting on the end of a pivot arm travels 2π times the radius of the arm for each revolution.

$$\text{Rotary power (W)} = 2\pi \times T \times \omega$$

where T = torque (N·m)

ω = angular velocity (rad/s)

2.13 *Tractor power equations* These equations aid in calculating power input requirements when an agricultural tractor is used to power materials-handling equipment.

2.14 *Drawbar power*

$$\text{Drawbar power (kW)} = FV_f/k$$

where F = force (kN)

V_f = forward speed (km/h)

k = constant

$$= \frac{3600 \text{ s/h}}{1000 \text{ m/km}}$$

2.15 *Power take off*

$$\text{Power take off (kW)} = 2\pi FRV/k = 2\pi TV/k$$

where F = tangential force (kN)
R = radius of force rotation (m)
V = speed (r/min)
T = torque (N·m)
k = constant
= 60 (s/min)

2.16 *Hydraulic power*

Hydraulic power (kW) = pQ

where p = gauge pressure (kPa)
Q = flow rate (m^3/s)

2.17 Gear and pulley equations

If a small gear (pinion) drives a large gear, the large gear rotates slower than the small gear, but has a greater torque. Similarly, if a large gear drives a small gear, the small gear rotates faster than the large gear, and has less torque.

$$\frac{V_g}{V_p} = \frac{r_p}{r_g}$$

where r_g = radius of the large gear
r_p = radius of the pinion
V_g = gear speed (r/min)
V_p = pinion speed (r/min)

The number of teeth on a gear is proportional to the radius.

$$\frac{V_g}{V_p} = \frac{M_p}{M_g}$$

where V_g = gear speed (r/min)
V_p = pinion speed (r/min)
M_g = number of teeth on the gear
M_p = number of teeth on the pinion

If a pulley drives a belt at a particular speed, the following equation defines the belt speed.

$$V = \frac{2\pi V_p r_p}{60}$$

where V = belt speed (m/s)
V_p = pulley rotational speed (r/min)
r_p = pulley radius (m)

The speed calculated this way represents the peripheral speed of the driving pulley. Neglecting slip, it also represents the peripheral speed of the driven pulley, which can also be given by the equation:

$$V = \frac{2\pi V_d r_d}{60}$$

where V_d = rotational speed of driven pulley (r/min)
r_d = radius of driven pulley (m)

2.18 Fan laws

The following equations define the relationship between the speed, capacity, pressure, and power requirements of fans.

$$\frac{Q_2}{Q_1} = \frac{V_2}{V_1}$$

$$\frac{p_2}{p_1} = \frac{V_2^2}{V_1^2}$$

$$\frac{P_2}{P_1} = \frac{V_2^3}{V_1^3}$$

where Q = capacity (volume/time)
V = rotational speed
p = static or total pressure
P = power

2.19 Bernoulli equation

Use the Bernoulli equation to equate the energy states of any set of points in an open fluid system. The equation includes terms to consider head energy contributed to or lost by components of the system.

$$\frac{V_1^2}{2g} + H_1 + \frac{p_1}{\gamma} + H_p = \frac{V_2^2}{2g} + H_2 + \frac{p_2}{\gamma} + H_t + H_L$$

where p/γ = pressure head (m)
$V^2/2g$ = velocity head (m)
H = elevation head (m)
p = pressure (kPa)
γ = specific weight (kN/m)
V = velocity (m/s)
g = gravitational constant
= 9.81 (m/s^2)
H_p = head supplied by a pump (m)
H_t = head loss to a turbine (m)
H_L = head loss to friction (m)

2.20 Heat transfer equations

Heat transfer equations define the following:

- conduction
- convection
- heat transfer across a surface
- thermal resistance
- radiation

2.21 *Conduction* Conduction refers to the transfer of heat from a region of higher temperature to a region of lower temperature. This heat transfer occurs via direct contact with stationary transfer media.

$$q = -\lambda A \, dT/dL$$

where q = rate of conductive heat transfer (W)

λ = thermal conductivity (W/(m·K))

A = cross-sectional area measured normal to direction of heat flow (m^2)

T = temperature (K)

L = distance in direction of heat flow (m)

dT/dL = temperature gradient in the direction of heat flow

$= (T_2 - T_1)/L$

2.22 *Convection* Convection refers to heat transfer by the combined actions of conduction, mixing, and energy storage. It involves the relocation of heat by liquid or gas in motion.

$$q = \bar{h}_c A (T_s - T_f)$$

where q = rate of convective heat transfer (W)

A = heat transfer area (m^2)

T_s = temperature of the surface (K)

T_f = temperature of the fluid at some specified location (K)

$\bar{h}_c$ = convective heat transfer coefficient ($W/(m^2 \cdot K)$)

2.23 *Heat transfer across a surface* Refer to Fig. 2 when using this equation.

$$q = A \times \bar{h} \times t$$

where q = heat flow (W)

A = surface area (m^2)

$\bar{h}$ = heat transfer coefficient ($W/(m^2 \cdot °C)$)

t = temperature difference (°C) between two materials

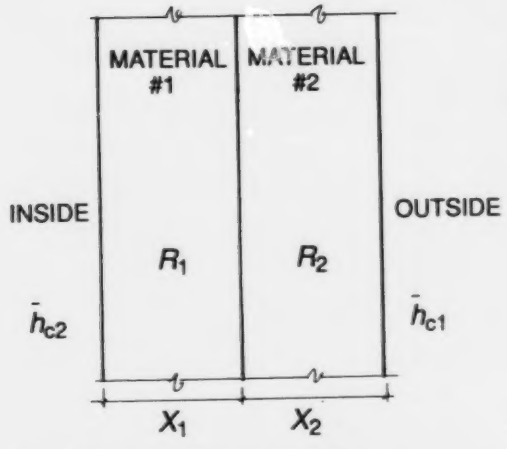


Fig. 2. Heat transfer across a surface.

2.24 *Thermal resistance*

$$R = R_c + R_t = 1/\bar{h}$$

where R_t = thermal resistance ($m^2 \cdot °C/W$)

$= R_1 + R_2 + R_3$ ... (Fig. 2)

R_c = convection resistance ($m^2 \cdot °C/W$)

$= 1/\bar{h}_{c1} + 1/\bar{h}_{c2}$

$\bar{h}$ = heat transfer coefficient ($W/(m^2 \cdot °C)$)

2.25 *Radiation* Radiation is heat transfer across a temperature gradient. It occurs in electromagnetic waves and so can penetrate a vacuum (e.g. sunshine).

A perfect radiator emits radiant energy from its surface at the following rate:

$$q = \sigma A T^4$$

where q = rate of radiant heat transfer (W)

σ = Stefan-Boltzmann constant

$= 5.67 \times 10^{-8}$ $W/(m^2 \cdot K^4)$

T = absolute temperature of the surface (K)

2.26 Equations relating to heating, ventilating, and air conditioning

Use these equations in situations involving heating, ventilating, or air conditioning (HVAC):

- heat gain from or to ventilation air
- perfect gas law

2.27 *Heat gain from or to ventilation air*

$$q = Q(h_o - h_i)$$

where q = rate of heat flow (kW)

Q = rate of airflow (kg/s)

h_o = specific enthalpy of outside air (kJ/kg)

h_i = specific enthalpy of inside air (kJ/kg)

2.28 *Perfect gas law*

$$pV = mRT$$

where p = absolute pressure (Pa)

V = total volume (m^3)

m = mass (kg)

R = constant

= 287 J/(kg·K) for dry air

T = absolute temperature (K)

2.29 Electrical parameters

The following equations are commonly used to determine the electrical power requirements of materials-handling equipment.

2.30 *Electrical power for alternating current*

$$P_{sp} = \frac{I \times E \times pf}{1000}$$

$$P_{tp} = \frac{I \times E \times pf \times 2.73}{1000}$$

where P_{sp} = single-phase power (kW)

P_{tp} = triple-phase power (kW)

E = voltage (V)

pf = power factor

I = amperage (A)

2.31 *Electrical power for direct current*

$$E = IR$$

$$P = EI$$

where E = voltage (V)

I = amperage (A)

R = electrical resistance (Ω)

P = power (W)

2.32 Structural parameters

Structural design parameters for the design of facilities handling agricultural materials are extremely numerous and diverse. Following are some basic relationships. For additional reference information, consult these publications:

- *Canadian Farm Buildings Handbook*
- *National Building Code of Canada*
- *Canadian Farm Building Code*
- *Midwest Plan Service Structures and Environment Handbook*
- *Engineering Design in Wood* (Limit States Design)
- *Portland Cements*
- *Handbook of Steel Construction*, Canadian Institute of Steel Construction
- *Canadian Foundation Engineering Manual*, Canadian Geotechnical Society

However, for all but the simplest designs rely on the expertise of structural and mechanical engineers.

2.33 *Direct stress* Consider a bar of any shape, subjected to two equal, opposite, and collinear loads acting through the centroid of the bar's cross section. Use the following equation to calculate the normal stress at any point on the bar perpendicular to the loads:

$$\sigma_d = F/A$$

where σ_d = direct stress (kPa)

F = force (kN)

A = cross-sectional area (m^2)

2.34 *Bending stress* To obtain normal bending stress at any point on a section perpendicular to the axis of a beam, use this equation:

$$\sigma_b = M/Z$$

where σ_b = bending stress (kPa)

M = bending moment (kN·m)

Z = section modulus (m^3)

$= c/I$

c = distance from neutral axis to the point at which the stress occurs (m)

I = moment of inertia about neutral axis (m^4)

2.35 *Torsional stress* Use the following equation to calculate the transverse shear stress on a bar at a point some distance from its axis. Note that torsional stress acts on a cross section perpendicular to the axis (Fig. 3).

$$\sigma_t = TL/J$$

where σ_t = transverse shear stress (kPa)

T = applied torque (kN·m)

L = distance from the axis (m)

J = polar moment of inertia (m^4)

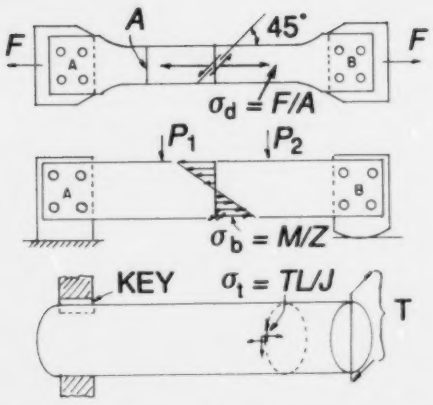


Fig. 3. Significant stresses as given by elementary stress formulas.

3 CONVERSION FACTORS

The tables in this section present an overview of the relationships between various SI units and other commonly encountered units of Imperial and United States origin. For more detailed information, consult the *Canadian Metric Practice Guide*, prepared by the Canadian Standards Association.

3.1 Imperial and United States systems of measurement

Table 1 lists an assortment of units of Imperial and United States origin and the factors required to convert from basic to derived units. Table 2 identifies the abbreviations used.

3.2 SI units

The *Système international d'unités* (International System of Units, abbreviated SI in all languages) was adopted in 1960. It includes three classes of units:

- basic units
- supplementary units
- derived units

The basic SI units include:

metre	(m)	the unit of length
second	(s)	the unit of time
kilogram	(kg)	the unit of mass
kelvin	(K)	the unit of thermodynamic temperature
ampere	(A)	the unit of electric current
candela	(cd)	luminous intensity
mole	(mol)	the amount of a substance

Supplementary SI units include:

radian	(rad)	plane angle
steradian	(sr)	solid angle

Table 3 lists SI derived units.

Table 1 Derived units within the Imperial (UK) and United States (US) systems of measurement (Basic unit × Conversion factor = Derived unit)

Quantity name	Basic unit	Conversion factor	Derived unit
Area	acre	43 560	ft^2
		1.562×10^{-3}	mi^2
		4840	yd^2
	$in.^2$	0.00694	ft^2
	mi^2	3.0976×10^6	yd^2
		2.7878×10^7	ft^2
	yd^2	9	ft^2
		1296	$in.^2$
	township	36	mi^2
Circle	angle	6.2832	radians
		360	degrees
Density	lb/ft^3	1.2843	lb/bushel (UK)
		1.2444	lb/bushel (US)
		0.16054	lb/gal (UK)
		0.13368	lb/gal (US)
		0.0135	t(short)/yd
		0.0120	t(long)/yd
Energy	Btu (International)	3.93×10^{-4}	hp·h
		777.97	ft·lb
Flow	ft^3/s	373.7	gal/min (UK)
		448.9	gal/min (US)
Force	lb (avdp.)	0.4643×10^{-4}	t (long)
		5×10^{-4}	t (short)
		16	oz (avdp.)
		7000	grains
		1.21528	lb (troy)
		14.5833	oz (troy)
	lb (troy)	12	oz (troy)
		5760	grains
Length	mi	1760	yd
		5280	ft
		0.8683	mi (nautical)
		8	furlong

(continued)

Table 1 Derived units (*concluded*)

Quantity name	Basic unit	Conversion factor	Derived unit
	ft	12	in.
	in.	1000	mil
	yd	3	ft
		36	in.
Mass	slug	32.174	lb
Power	hp	0.70696	Btu/s
		33 000	ft·lb/min
Pressure	lb/in.^{2}	0.0680	atmosphere
		0.0689	bar
		144	lb/ft^2
		16	oz/in.^{2}
Velocity	mi/h	0.01666	mi/min
		1.4667	ft/s
Viscosity	poise	0.0672	lb/ft·s
Volume	ft^3	0.03703	yd
		0.7786	bushel (UK)
		0.8036	bushel (US)
		12	board ft
		6.229	gal (UK)
		24.916	liquid qt (UK)
		49.831	liquid pt (UK)
		996.614	liquid oz (UK)
		957.507	liquid oz (US)
		1728	in.^{3}
	in.^{3}	0.5767	liquid oz (UK)
	gal (UK)	1.2009	gal (US)
		4	qt (UK)
	gal (UK)	8	pt (UK)
		32	gill
		160	liquid oz (UK)
	gal (US)	4	qt (US)
		8	pt (US)
		32	gill
		128	liquid oz (US)
	qt (UK)	1.2009	qt (US)
	pt (UK)	1.2009	pt (US)
	liquid oz (UK)	0.9608	oz (US)

Table 2 Abbreviations for units

Abbreviation	Unit
avdp.	avoirdupois
Btu	British thermal unit
Btu/s	British thermal unit per second
cal	calorie
ft	foot
ft^2	square foot
ft^3	cubic foot
ft^3/s	cubic foot per second
ft·lb	foot·pound
ft·lb/min	foot·pound per minute
ft/s	foot per second
gal	gallon
gal/min	gallon per minute
hp	horsepower
in.	inch
in.^{2}	square inch
in.^{3}	cubic inch
lb	pound
lbf	pound-force
lb/ft^2	pound per square foot
lb/ft^3	pound per cubic foot
lb/gal	pound per gallon
lb/in.^{2}	pound per square inch
mi	mile
mi^2	square mile
mi/min	mile per minute
mi/h	mile per hour
oz	ounce
oz/in.^{2}	ounce per square inch
pt	pint
qt	quart
t	ton
t/yd	ton per yard
yd	yard
yd^2	square yard

Table 3 SI derived units

Quantity	Unit	SI symbol	Formula
Acceleration	metre per second squared		m/s^2
Activity (of a radioactive source)	disintegration per second		(disintegration)/s
Angular acceleration	radian per second squared		rad/s^2
Angular velocity	radian per second		rad/s
Area	square metre		m^2
Density	kilogram per cubic metre		kg/m^3
Electrical capacitance	farad	F	A·s/V
Electrical conductance	siemens	S	A/V
Electrical field strength	volt per metre		V/m
Electrical inductance	henry	H	V·s/A
Electrical potential difference	volt	V	W/A
Electrical resistance	ohm	Ω	V/A
Electromotive force	volt	V	W/A
Energy	joule	J	N·m
Entropy	joule per kelvin		J/K
Force	newton	N	$kg·m/s^2$
Frequency	hertz	Hz	(cycle)/s
Illuminance	lux	lx	lm/m^2
Luminance	candela per square metre		cd/m^2
Luminous flux	lumen	lm	cd·sr
Magnetic field strength	ampere per metre		A/m
Magnetic flux	weber	Wb	V·s
Magnetic flux density	tesla	T	Wb/m^2
Magnetomotive force	ampere	A	
Power	watt	W	J/s
Pressure	pascal	Pa	N/m^2
Quantity of electricity	coulomb	C	A·s
Quantity of heat	joule	J	N·m
Radiant intensity	watt per steradian		W/sr
Specific heat	joule per kilogram kelvin		J/kg·K
Stress	pascal	Pa	N/m^2
Thermal conductivity	watt per metre kelvin		W/m·K
Velocity	metre per second		m/s
Viscosity, dynamic	pascal second		Pa·s
Viscosity, kinematic	square metre per second		m^2/s
Voltage	volt	V	W/A
Volume	cubic metre		m^3
Wavenumber	reciprocal metre		(wave)/m
Work	joule	J	N·m

3.3 Multiples of SI units

The SI prefixes and their symbols listed in Table 4 are used to form names and symbols of decimal multiples of SI units. Attach the prefix name directly to the unit name.

3.4 Conversion to SI units

Table 5 lists the factors required to convert Imperial and United States units to SI units.

Table 4 SI unit prefixes

Multiplying factor	Prefix	SI symbol	Multiplying factor	Prefix	SI symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	μ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10^{1}	deca	da	10^{-18}	atto	a

Table 5 Conversion factors: Imperial (UK) and United States (US) units to SI units

Quantity	Imperial and US units	Multiplication factor	SI units
Acceleration	1 ft/s^2	0.304 8	m/s^2
Area	1 ft^2	0.092 903	m^2
	1 in.^{2}	6.451 6	cm^2
	1 acre	0.404 687	ha
	1 arpent (French measure)	0.341 889	ha
	1 mi^2	2.589 988	km^2
	1 legal subdivision (40 acres)	0.161 874	km^2
	1 perch (French measure)	34.188 94	m^2
Capacity			
Heat	1 Btu/°F	1.899 101	kJ/K
Specific	1 Btu/(lb·°F)	4.186 8	kJ/(kg·K)
Coefficient			
Heat transfer	1 Btu/(h·ft^2·°F)	5.678 263	W/(m·K)
Linear expansion	1 F^{-1}	1.8	K^{-1}
Conductance			
Electrical	1 mho	1	S
Conductivity			
Electrical	1 mho/ft	3.280 840	S/m
Thermal	1 Btu·ft/(h·ft^2·°F)	1.730 735	W/(m·K)
Consumption			
Fuel	1 gal (UK)/h	4.546 090	L/h
	1 gal (US)/h	3.785 412	L/h
	1 mi/gal (UK)	2.824 5	L/100 km
	1 mi/gal (US)	2.352 1	L/100 km
Density			
Current	1 A/in.^{2}	1.550 003	kA/m^2
Magnetic flux	1 kilogauss	0.1	T
Mass	1 lb/yd^3	0.593 276	kg/m^3
	1 lb/in.^{3}	27 679.90	kg/m^3
	1 lb/ft^3	16.018 46	kg/m^3
	1 lb/liquid gal (UK)	0.099 776	kg/L
	1 lb/liquid gal (US)	0.119 826	kg/L
Heat flow	1 Btu/(h·ft^2)	3.154 591	W/m^2
Energy			
Work, enthalpy	1 ft·lbf	1.355 818	J
Quantity of heat	1 Btu	1.055 056	kJ
	1 kcal	4.186 8	kJ
	1 kW·h	3.6	MJ
	1 ft·poundal	0.042 140	J
	1 hp·h	2.684 520	MJ
	1 hp·h	0.745 700	kWh
Per area	1 Btu/ft^2	0.011 356	MJ/m^2
Specific	1 cal/g	4.186 8	J/g
	1 Btu/lb	2.326	kJ/kg

(continued)

Table 5 Conversion factors: Imperial (UK) and United States (US) units to SI units (*continued*)

Quantity	Imperial and US units	Multiplication factor	SI units
Flow			
Mass rate	1 lb/min	0.453 592	kg/min
	1 t (short)/h	0.907 184	t/h, Mg/h
Volume	1 ft^3/s	0.028 317	m^3/s
	1 gal (UK)/s	4.546 090	L/s
	1 gal (US)/s	3.785 412	L/s
	1 gal (UK)/s	0.004 546	m^3/s
	1 gal (US)/s	0.003 785	m^3/s
	1 gal (UK)/min	0.075 768	L/s
	1 gal (US)/min	0.063 090	L/s
	1 oz (UK)/s	28.413 062	mL/s
	1 oz (US)/s	29.573 53	mL/s
Flux (magnetic)	1 maxwell	1.0×10^{-8}	Wb
Force	1 lbf	4.448 222	N
	1 ozf	0.278 014	N
	1 poundal	0.138 255	N
	1 kgf	9.806 6	N
	1 dyne	1.0×10^{-5}	N
Per length	1 lbf/ft	14.593 90	N/m
	1 lbf/in.	0.175 127	N/mm
Heat	1 cal/g	4.186 8	kJ/kg
Specific	1 Btu/lb	2.326	kJ/kg
Illuminance	1 fc	10.763 91	lx
Impedance			
Damping	1 lbf·s/ft	14.593 90	N·s/m
Intensity			
Luminous	1 candlepower	1.0	cd
Length	1 mi	1.609 344	km
	1 rod	5.029 210	m
	1 yd	0.914 4	m
	1 ft	0.304 8	m
	1 in.	2.54	cm
	1 in.	25.4	mm
	1 mil	0.025 4	mm
	1 µin.	0.025 4	µm
	1 micron	1.0	µm
	1 µin.	25.4	nm
Luminance	1 foot lambert	3.426 259	cd/m^2
Magnetization	1 A/in.	39.370 08	A/m

(*continued*)

Table 5 Conversion factors: Imperial (UK) and United States (US) units to SI units (*continued*)

Quantity	Imperial and US units	Multiplication factor	SI units
Mass	1 t (long)	1.016 047	t, Mg
	1 t (short)	0.907 185	t, Mg
	1 lb (avdp.)	0.453 592	kg
	1 slug	14.593 90	kg
	1 oz (avdp.)	28.349 52	g
	1 carat (diamond)	200	mg
Per area	1 oz/yd^2	33.905 75	g/m^2
	1 lb/ft^2	4.882 428	kg/m^2
	1 oz/ft^2	305.151 7	g/m^2
	1 lb/acre	1.120 851	kg/ha
	1 t (short)/acre	2.241 702	t/ha
Per length	1 lb/ft	1.488 164	kg/m
	1 lb/yd	0.496 055	kg/m
Per time	1 t (short)/h	0.907 185	t/h, Mg/h
Modulus			
Section	1 in.^{3}	16 387.06	mm^3
	1 in.^{3}	16.387 06	cm^3
Moment			
Of area	1 in.^{4}	416 231.4	mm^4
	1 in.^{4}	41.623 14	cm^4
Of force, torque, bending moment	1 lbf·in.	0.112 985	N·m
	1 lbf·ft	1.355 818	N·m
	1 kgf·cm	0.098 066	N·m
	1 ozf·in.	7.061 552	mN·m
Of inertia, mass	1 lb·ft^2	0.042 140	kg·m^2
Of mass	1 oz·in.	0.720 078	g·m
Momentum			
Linear	lb·ft/s	0.138 255	kg·m/s
Angular	lb·ft^2/s	0.042 140	kg·m^2/s
Power	1 Btu/min	17.584 27	W
	1 Btu/h	0.293 071	W
	1 hp	0.745 700	kW
Per area	1 Btu/ft^2·h	3.154 591	W/m^2
Pressure	1 lbf/in.^{2} (psi)	6.894 757	kPa
	1 in. Hg (60°F)	3.376 85	kPa
	1 in. H_2O (60°F)	0.248 84	kPa
	1 mm Hg (0°C)	0.133 322	kPa
	1 kgf/cm	98.066 5	kPa
	1 bar	100.0	kPa
	1 lbf/ft	0.047 880	kPa
	1 atm (normal = 760 torr)	101.325	kPa
Spring rate			
Torsional	1 lbf·ft/deg	1.355 818	N·m/deg

(*continued*)

Table 5 Conversion factors: Imperial (UK) and United States (US) units to SI units (*concluded*)

Quantity	Imperial and US units	Multiplication factor	SI units
Strength			
Electrical	1 V/ft	3.280 840	V/m
Magnetic	1 oersted	79.577 47	A/m
Impact	1 ft·lbf	1.355 818	J
Stress	1 lbf/in.^{2}	0.006 895	MPa
Temperature	°F	(°F – 32)/1.8	°C
	°R	1/1.8	K
Interval	°F	0.555 5	°C or K
Tension			
Surface	1 lbf/in.	175 126.8	mN/m
	1 dyne/cm	1.0	mN/m
Thermal diffusivity	1 ft^2/h	0.092 903	m^2/h
Toughness	1 ksi·in.$^{0.5}$	1.098 843	MPa·m$^{0.5}$
Velocity	1 mi/h	1.609 344	km/h
	1 ft/min	0.304 8	m/min
	1 ft/s	0.304 8	m/s
	1 in./s	25.4	mm/s
Viscosity			
Dynamic	1 centipoise	1.0	mPa·s
Kinematic	1 centistoke	1.0	mm^2/s
Volume	1 yd^3	0.764 555	m^3
	1 ft^3	0.028 317	m^3
	1 bushel (UK)	36.368 72	L
	1 bushel (US)	35.239 07	L
	1 ft^3	28.316 85	L
	1 in.^{3}	0.016 387	L
	1 in.^{3}	16.387 06	cm^3
	1 gal (UK)	4.546 090	L
	1 gal (US)	3.785 412	L
	1 qt liquid (UK)	1.136 522	L
	1 qt liquid (US)	0.946 353	L
	1 pt liquid (UK)	0.568 261	L
	1 pt liquid (US)	0.473 176	L
	1 oz liquid (UK)	28.413 062	mL
	1 oz liquid (US)	29.573 53	mL
	1 acre·ft	1233.489	m^3
	1 acre·ft	1.233 489	dam^3
	1 bushel (UK)	0.036 369	m^3
	1 bushel (US)	0.035 239	m^3
Per area	1 liquid gal/acre (UK)	11.233 633	L/ha
	1 liquid gal/acre (US)	9.353 958	L/ha

3.5 Nominal dimensions of various gauges

Table 6 illustrates the relationships among several systems for measuring metal products, including wire, wrought iron, and sheet and hoop metal. The values in the table are in approximate decimals of an inch. Metric wire gauge is 10 times the diameter in millimetres.

The Washburn and Moen (W and M) gauge, called also the steel-wire gauge, applies to steel wire. Use the American Wire, or Brown and Sharpe gauge, for nonferrous wire and sheet such as monel, bronze, copper, aluminum, and brass wires. This system may also be used for iron wire. The Birmingham (BWG) system primarily applies to iron or brass wire, although it may also be used for copper plate, for steel plate 12 gauge and heavier, and for steel tubes.

Because many gauges are in use for various shapes and metals, state the thickness in thousandths when specifying gauge number.

Table 6 Systems for measuring metal products

Gauge number	A	B	C	D	E	F
0000000	.....	0.4900	.....	.....	0.6666	0.500
000000	.....	0.4615	.....	.....	0.6250	0.464
00000	.....	0.4305	.....	.....	0.5883	0.432
0000	0.460	0.3938	0.454	.....	0.5416	0.400
000	0.410	0.3625	0.425	.....	0.5000	0.372
00	0.365	0.3310	0.380	.....	0.4452	0.348
0	0.325	0.3065	0.340	.....	0.3964	0.324
1	0.289	0.2830	0.300	.....	0.3532	0.300
2	0.258	0.2625	0.284	.....	0.3147	0.276
3	0.229	0.2437	0.259	0.239	0.2804	0.252
4	0.204	0.2253	0.238	0.224	0.2500	0.232
5	0.182	0.2070	0.220	0.209	0.2225	0.212
6	0.162	0.1920	0.203	0.194	0.1981	0.192
7	0.144	0.1770	0.180	0.179	0.1764	0.176
8	0.128	0.1620	0.165	0.164	0.1570	0.160
9	0.114	0.1483	0.148	0.150	0.1398	0.144
10	0.102	0.1350	0.134	0.135	0.1250	0.128
11	0.091	0.1205	0.120	0.120	0.1113	0.116
12	0.081	0.1055	0.109	0.105	0.0991	0.104
13	0.072	0.0915	0.095	0.090	0.0882	0.092
14	0.064	0.0800	0.083	0.075	0.0785	0.080
15	0.057	0.0720	0.072	0.067	0.0699	0.072
16	0.051	0.0625	0.065	0.060	0.0625	0.064
17	0.045	0.0540	0.058	0.054	0.0556	0.056
18	0.040	0.0475	0.049	0.0478	0.0495	0.048
19	0.036	0.0410	0.042	0.0418	0.0440	0.040
20	0.032	0.0348	0.035	0.0359	0.0392	0.036
21	0.0285	0.0317	0.032	0.0329	0.0349	0.032
22	0.0253	0.0286	0.028	0.0299	0.0313	0.028
23	0.0226	0.0258	0.025	0.0269	0.0278	0.024
24	0.0201	0.0230	0.022	0.0239	0.0248	0.022
25	0.0179	0.0204	0.020	0.0209	0.0220	0.020

(continued)

Table 6 Systems for measuring metal products (*concluded*)

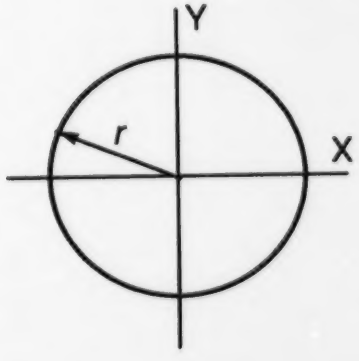
Gauge number	A	B	C	D	E	F
26	0.0159	0.0181	0.018	0.0188	0.0196	0.0180
27	0.0142	0.0173	0.016	0.0172	0.0175	0.0164
28	0.0126	0.0162	0.014	0.0156	0.0156	0.0148
29	0.0113	0.0150	0.013	0.0141	0.0139	0.0136
30	0.0100	0.0140	0.012	0.0125	0.0123	0.0124
31	0.0089	0.0132	0.010	0.0109	0.0110	0.0116
32	0.0080	0.0128	0.009	0.0102	0.0098	0.0108
33	0.0071	0.0118	0.008	0.0094	0.0087	0.0100
34	0.0063	0.0104	0.007	0.0086	0.0077	0.0092
35	0.0056	0.0095	0.005	0.0078	0.0069	0.0084
36	0.0050	0.0090	0.004	0.0070	0.0061	0.0076
37	0.0045	0.0085	.....	0.0066	0.0054	0.0068
38	0.0040	0.0080	.....	0.0062	0.0048	0.0060
39	0.0035	0.0075	.....	.....	0.0043	0.0052
40	0.0031	0.0070	.....	.....	0.0039	0.0048
41	.....	0.0066	.....	.....	0.0034	0.0044
42	.....	0.0062	.....	.....	0.0031	0.0040
43	.....	0.0060	.....	.....	0.0027	0.0036
44	.....	0.0058	.....	.....	0.0024	0.0032
45	.....	0.0055	.....	.....	0.0022	0.0028
46	.....	0.0052	.....	.....	0.0019	0.0024
47	....	0.0050	.....	.....	0.0017	0.0020
48	.....	0.0048	.....	.....	0.0015	0.0016
49	.....	0.0046	.....	.....	0.0014	0.0012
50	.....	0.0044	.....	.....	0.0012	0.0010

A = American or Brown Sharpe gauge
B = US Steel Wire or Washburn Moen or Roebling or American Steel Wire Co. gauge
C = Birmingham or Stubs iron wire gauge
D = US standard gauge
E = Standard Birmingham gauge
F = Imperial standard wire gauge (British legal standard)

4 PROPERTIES OF GEOMETRIC SHAPES AND VOLUMES

4.1 Properties of geometric shapes

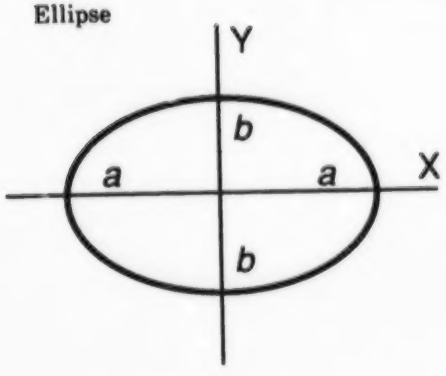
Circle



Circumference $2\pi r$
Area πr^2
$I_{xx} = I_{yy}$ $\pi r^4/4$
Definition The locus of all points equidistant from a fixed point

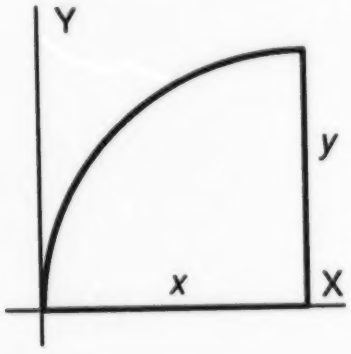
Note: throughout sections 4.1 and 4.2 the following symbols occur:
I = moment of inertia
Z = section modulus
$\bar{y}$ = distance from Y axis to the centroid
$\bar{x}$ = distance from X axis to the centroid

Ellipse



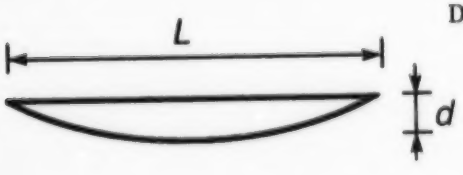
Circumference	$2\pi((a^2 + b^2)/2)^{0.5}$
Area	πab
I_{xx}	$\pi ab^3/4$
I_{yy}	$\pi a^3 b/4$
Definition	The locus of all points the sum of whose distance from two fixed points is constant
Eccentricity	$e = c/a$, where $c^2 = a^2 - b^2$

Parabola (area shown)



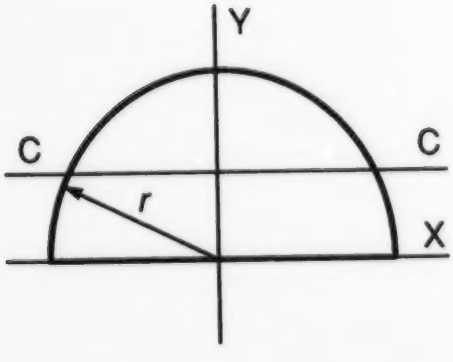
Total perimeter	$(y^2 + 4x^2/3)^{0.5} + x + y$
Area	$2xy/3$
$\bar{y}$	$3y/8$
$\bar{x}$	$3x/5$
Definition	The locus of all points equidistant from a fixed point and a fixed line

Catenary



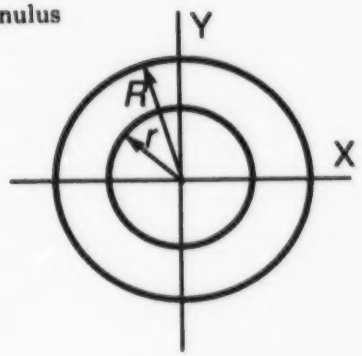
Length of arc	$L[1 + 2/3(2d/L)^2]$ approximately, if $d << L$
Definition	A curve made by a cord of uniform weight suspended between two points

Semicircle



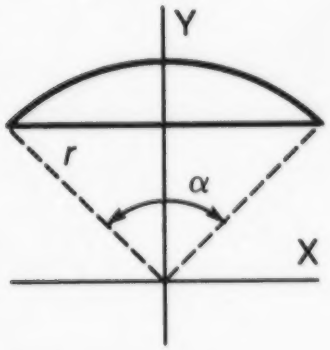
Perimeter	$\pi r + 2r$
Area	$\pi r^2/2$
$I_{xx} = I_{yy}$	$\pi r^4/8$
I_{cc}	$0.11r^4$
$\bar{y}$	$4r/3\pi = 0.424r$

Annulus



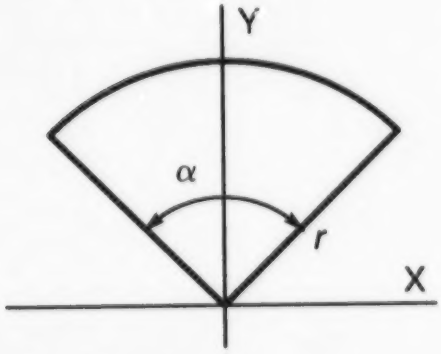
Perimeter	$2\pi R + 2\pi r$
Area	$\pi R^2 - \pi r^2$
$I_{xx} = I_{yy}$	$\pi R^4/4 - \pi r^4/4$
Definition	Two concentric circles of different radii

Segment of a circle



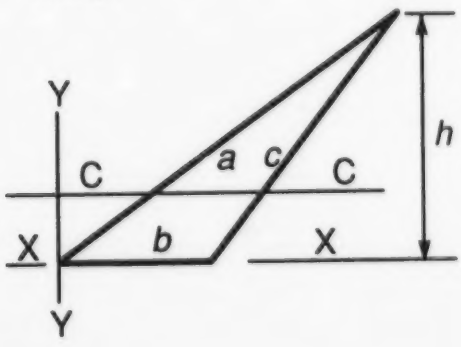
Perimeter	$2r\,a + 2r(\sin a)$, where a is expressed in radians
Arc length	$2ra$
Area	$r^2(a - \sin a \cos a)$
I_{xx}	$\dfrac{r^4(a + \sin a \cos a - 2 \sin a \cos^3 a)}{4}$
I_{yy}	$\dfrac{r^4(a - \sin a \cos a - 2/3 \sin^3 a \cos a)}{4}$
$\bar{y}$	$\dfrac{2r \sin^3 a}{3(a - \sin a \cos a)}$

Sector of a circle



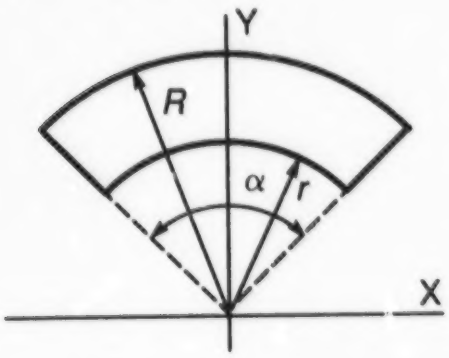
Perimeter	$2ra + 2r$, where a is expressed in in radians
Arc length	$2ra$
Area	ar^2
I_{xx}	$r^4(a + \sin a \cos a)/4$
I_{yy}	$r^4(a - \sin a \cos a)/4$
$\bar{y}$	$\dfrac{2r\,(\sin a)}{3a}$

Triangle



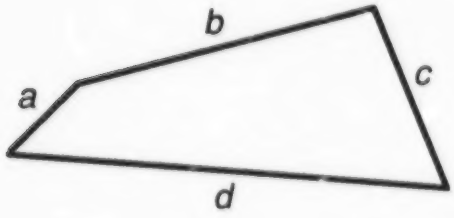
Perimeter	$a + b + c$
Area	$bh/2$
I_{xx}	$bh^3/12$
I_{cc}	$bh^3/36$
$\bar{y}$	$h/3$
$\bar{x}$	On median

Sector of annulus



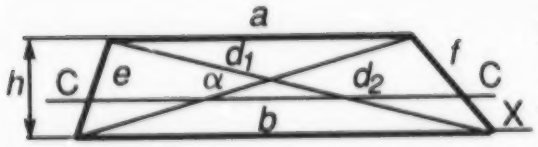
Total perimeter	$2\alpha(R + r) + 2(R - r)$
Large arc length	$2R\alpha$
Small arc length	$2r\alpha$
Area	$\alpha R^2 - \alpha r^2$
I_{xx}	$\frac{(R^4 - r^4)(\alpha + \sin\alpha\cos\alpha)}{4}$
I_{yy}	$\frac{(R^4 - r^4)(\alpha - \sin\alpha\cos\alpha)}{4}$
$\bar{y}$	$\frac{2(R^2 + Rr + r^2)\sin\alpha}{(R + r)3\alpha}$

Quadrilateral



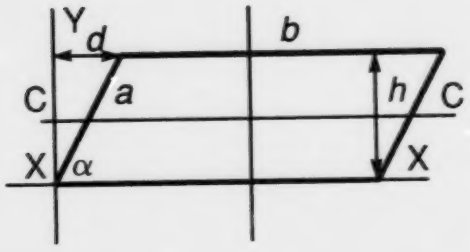
Perimeter	$a + b + c + d$
Area	Area of the two constituent triangles
I	Sum of the moments of inertia for composite triangles and rectangles
$\bar{y}$	See section 4.10
Definition	Area enclosed by four intersecting straight lines

Trapezoid



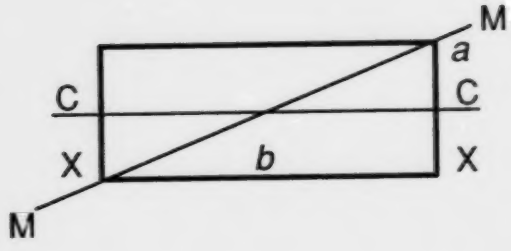
Perimeter	$a + e + b + f$
Area	$0.5(a + b)h = 0.5(d_1 d_2)\sin\alpha$
I_{xx}	$h^3(3a + b)/12$
I_{cc}	$\frac{h^3}{36}\frac{(a^2 + 4ab + b^2)}{(a + b)}$
$\bar{y}$	$\frac{h^3}{3}\frac{(2a + b)}{(a + b)}$
Definition	A quadrilateral with two sides parallel

Parallelogram



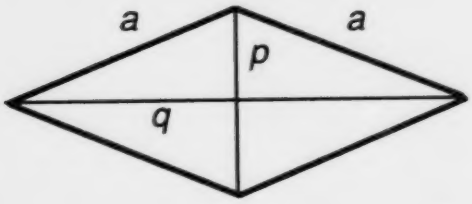
Perimeter	$2a + 2b$
Area	bh
	$ab \sin \alpha$
I_{xx}	$(1/3)bh^3$
I_{yy}	$\frac{bh}{6}(2b^2 + 1.5d^2 + 3bd)$
I_{cc}	$\frac{1}{2}bh^3(b^2 + d^2)$
$\bar{x}$	$\frac{(b + d)}{2}$
$\bar{y}$	$h/2$
Definition	A quadrilateral with two pairs of parallel sides

Rectangle



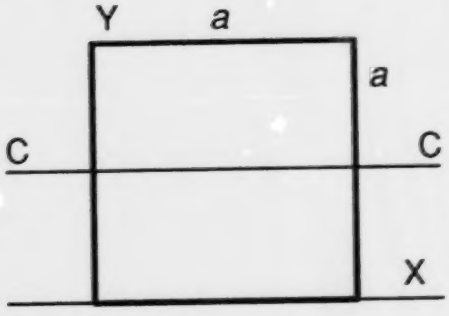
Perimeter	$2a + 2b$
Area	ab
I_{xx}	$ba^3/3$
I_{cc}	$ba^3/12$
I_{mm}	$\frac{a^3b^3}{6(a^2 + b^2)}$
Definition	A parallelogram in which all vertices are at right angles

Rhombus



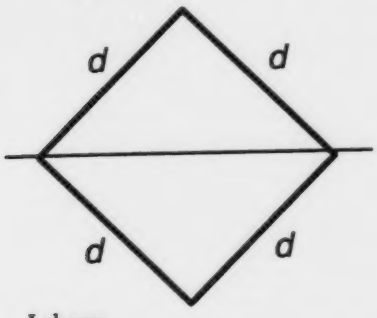
Perimeter	$4a$
Area	$pq/2$
	$p^2 + q^2 = 4a^2$
Definition	A parallelogram in which all sides are of equal length

Square



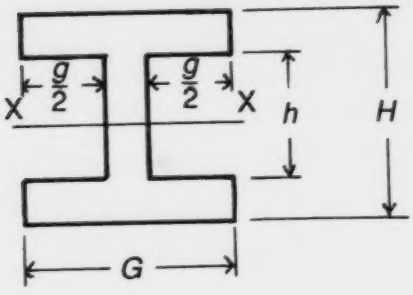
Perimeter	$4a$
Area	a^2
$I_{xx} = I_{yy}$	$a^4/3$
I_{cc}	$a^4/12$
$\bar{y}$	$a/2$
Definition	A rectangle with sides of equal length

Square
(Axis of moments on diagonal)



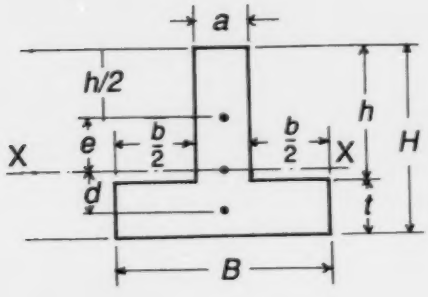
Perimeter	$4d$
Area	d^2
I	$d^4/12$
Z	$d^3/6 \times 2^{0.5}$ or $d^3/6\ \sqrt{2}$

I shape



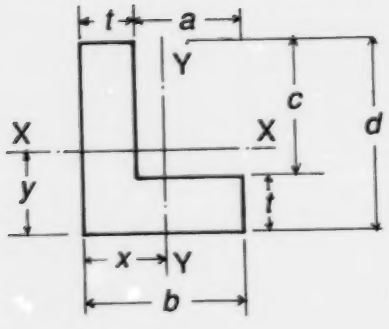
Perimeter	$2(G + H + g)$
Area	$GH - gh$
I_{xx}	$(1/12)\,(GH^3 - gh^3)$
Z_x	$(GH^3 - gh^3)/6H$

T shape



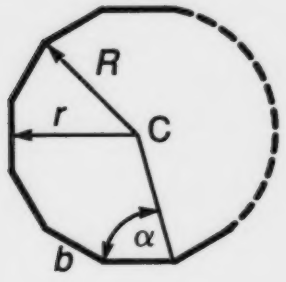
Perimeter	$BH - bh$
Area	$Bt + a(H - t)$
I_{xx}	$\frac{Bt^3}{12} + (Bt)d^2 + \frac{ah^3}{12} + (ah)e^2$

Angle



Perimeter	$2b + 2d$
Area	$t(b + c)$
I_x	$\frac{1}{3}\,[t(d - y)^3 + by^3 - a(y - t)^3]$
I_y	$\frac{1}{3}\,[t(b - x)^3 + dx^3 - c(x - t)^3]$

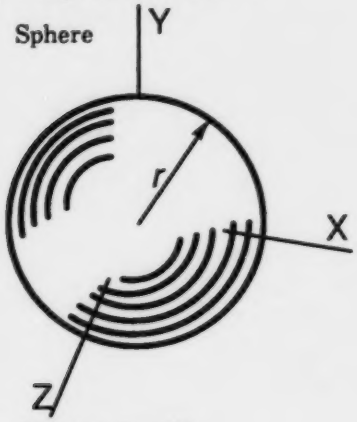
Regular polygon



Perimeter	nb, where n represents the number of sides
Area	$1/2\ nbr$
r	$b/2 \tan a$
a	$\frac{(n-2)}{2n}\ 180°$
I_{cc}	$\frac{nbr}{12}\ (R^2 + 2r^2)$

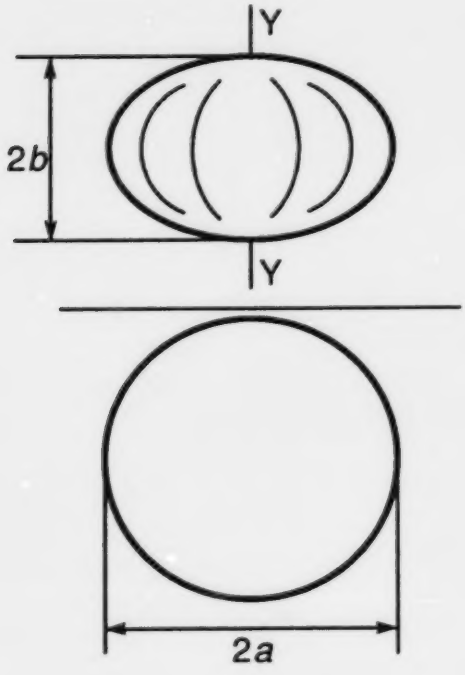
4.2 Properties of solids

Sphere



Surface area	$4\pi r^2$
Volume	$\frac{4}{3}\ \pi r^3$

Oblate spheroid

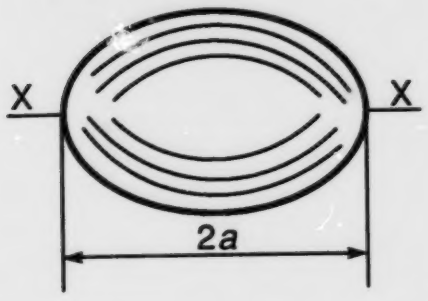


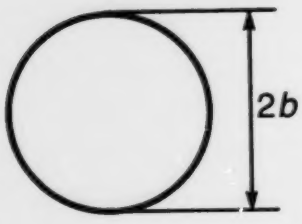
Surface area	$2\pi a^2 + \frac{\pi b^2}{e}\ \ln \frac{(1+e)}{(1-e)}$ $= \frac{4\pi a}{2^{0.5}}\ (a^2 + b^2)^{0.5}$(app.)

where a = semi-major axis
b = semi-minor axis
e = eccentricity $= \frac{(a^2 + b^2)^{0.5}}{a}$

Volume	$\frac{4}{3}\ \pi a^2 b$
Definition	Ellipse rotated about its minor axis ($2b$)

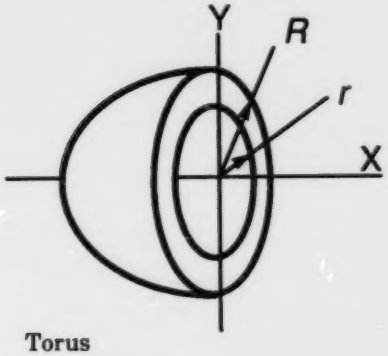
Prolate spheroid





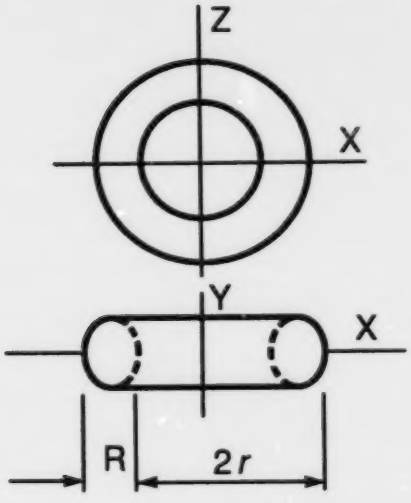
Surface area	$2\pi b^2 + 2\pi \frac{ab}{e} \sin^{-1} e$ $= \frac{4\pi b}{2} (a^2 + b^2)^{0.5}$
where	a = semi-major axis b = semi-minor axis e = eccentricity $= \frac{(a^2 + b^2)^{0.5}}{ab^2}$
Volume	$\frac{4\pi}{3} ab^2$
Definition	Ellipse rotated about its major axis ($2a$)

Hemispherical shell (for hemisphere, let $r = 0$)



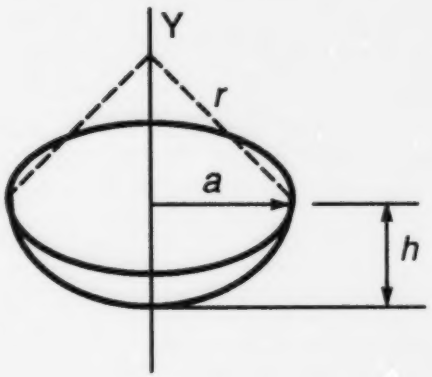
Area	$3\pi R^2 + \pi r^2$
Volume	$\frac{2}{3}\pi R^3 - \frac{2}{3}\pi r^3$
$\bar{x}$	$\frac{3(R^4 - r^4)}{8(R^3 - r^3)}$ or $r/2$ (if thin walled)

Torus



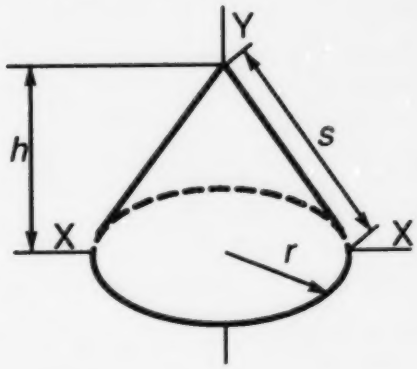
Surface area	$4\pi^2 Rr$
Volume	$2\pi^2 Rr^2$

Spherical segment



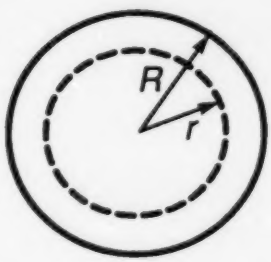
Curved area	$2\pi rh$
Total surface	$2\pi rh + \pi a^2$
Volume	$\frac{\pi}{6} h\,(3a^2 + h^2)$ where $a = h(2r - h)$ or $\pi h^2(r - \frac{h}{3})$
$\bar{y}$ (solid)	$\frac{3\,(2r - h)^2}{4\ 3r - h}$
$\bar{y}$ (convex surface)	$r - \frac{h}{2}$

Right circular cone



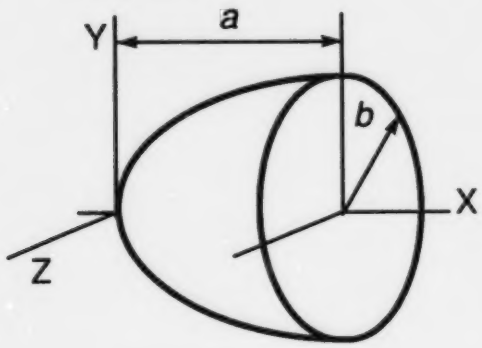
Lateral surface	πrs where $s = \sqrt{h^2 + r^2}$
Total surface	$\pi rs + \pi r^2$
Volume	$\frac{\pi}{3} r^2 h$
$\bar{y}$ (solid)	$h/4$
$\bar{y}$ (surface)	$h/3$

Hollow sphere



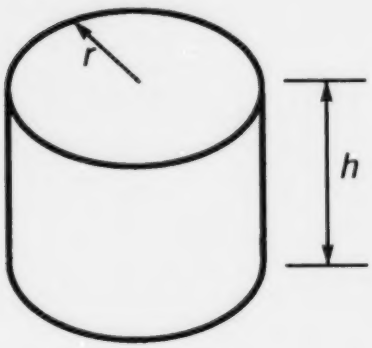
Surface area	$4\pi R^2 + 4\pi r^2$
Volume	$\frac{4}{3}\pi R^3 - \frac{4}{3}\pi r^3$

Paraboloid



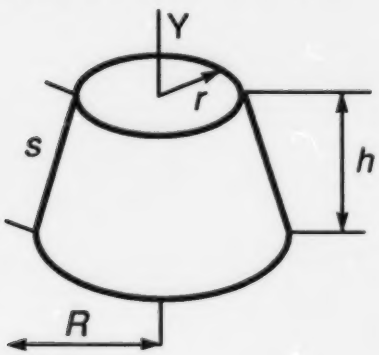
Surface area	$\frac{4\pi b}{3a^2}(b^2 + a^2)^{1.5} - (b/2)^3$
Volume	$\frac{1}{2}\pi a b^2$

Cylinder



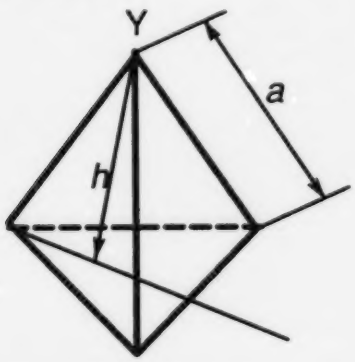
Surface area	$2\pi rh + 2\pi r^2$
Volume	$\pi r^2 h$

Frustum of a cone



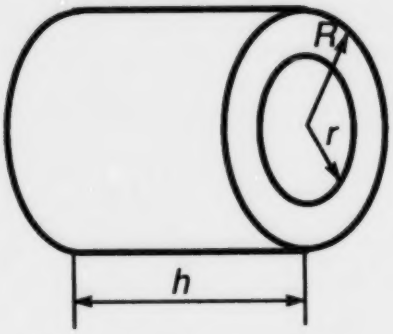
Surface area	$\pi s(R + r) + \pi R^2 + \pi r^2$ where $s = (h^2 + (R - r)^2)^{0.5}$
Volume	$\frac{1}{3}\pi h(R^2 + Rr + r^2)$
$\bar{y}$	$\frac{h}{4}\frac{(R^2 + 2Rr + 3r^2)}{(R^2 + Rr + r^2)}$

Tetrahedron



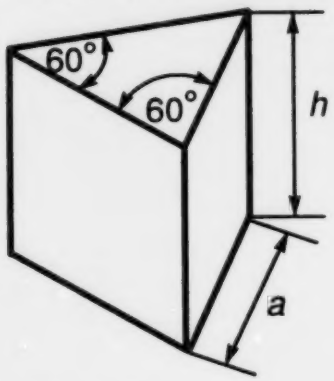
Surface area	$3^{0.5}a^2$
Volume	$a^3/(6(2)^{0.5})$
$\bar{y}$	$h/4$ where $h = (2/3)^{0.5}a$

Hollow cylinder



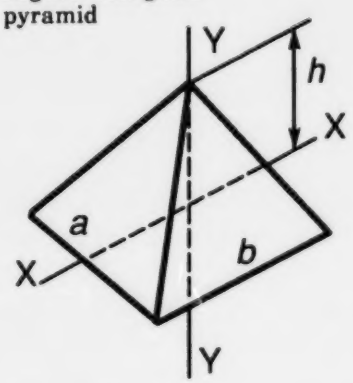
Surface area	$2\pi Rh + 2\pi rh + 2\pi R^2 - 2\pi r^2$
Volume	$\pi R^2 h - \pi r^2 h$

Triangular prism



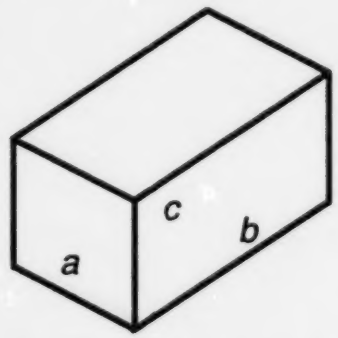
Surface area	$\frac{3}{2}\sqrt{3}\,a^3 h$
Volume	$\frac{(3)^{0.5}}{4}\,a^2 h$

Right rectangular pyramid



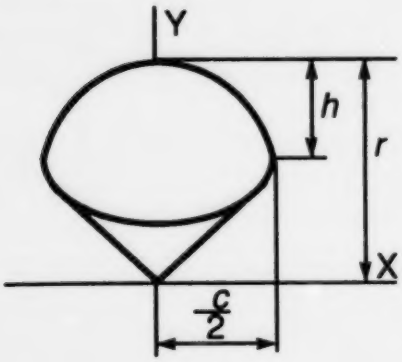
Surface area	$a(b^2/4 + h^2)^{0.5} + b(a^2/4 + h^2)^{0.5} + ab$
Volume	$abh/3$
$\bar{y}$ (solid)	$h/4$
$\bar{y}$ (slant surfaces)	$h/3$

Rectangular prism



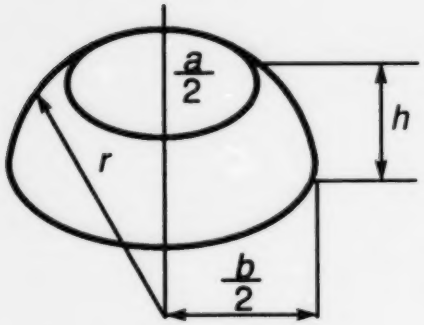
Surface area	$2ab + 2ac + 2bc$
Volume	abc

Spherical sector



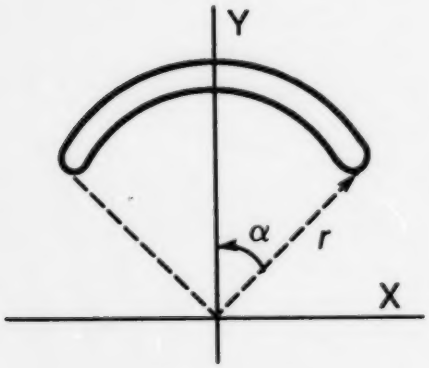
Surface area	$\frac{\pi r}{2}(4h + c)$
Volume	$\frac{2\pi}{3} r^2 h$
$\bar{y}$ (solid)	$\frac{3}{8}(2r - h)$
$\bar{y}$ (surface)	$\frac{h^2 + (r - h)(2h + c/3)}{2h + c/2}$

Zone of spherical surface



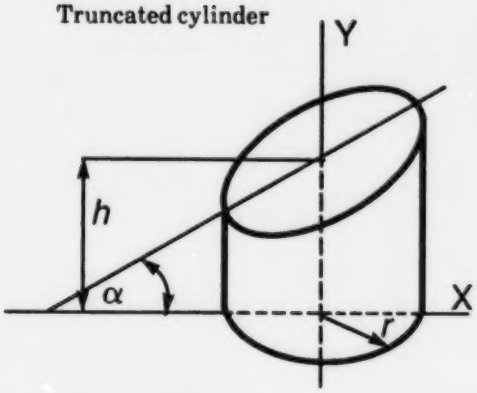
Area	$2\pi r h$
Volume	$\frac{\pi h}{24}(3a^2 + 3b^2 + 4h^2)$
$\bar{y}$	$h/2$

Circular rod

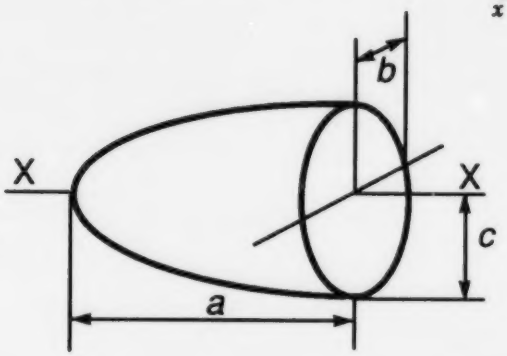


$\bar{y}$	$\frac{r \sin \alpha}{\alpha}$

Truncated cylinder	Area	$2\pi rh + \pi r^2\left(\frac{1}{\cos\alpha} + 1\right)$
	Volume	$\pi r^2 h$
	$\bar{y}$	$\frac{h}{2} + \frac{(r\tan\alpha)^2}{8h}$
	$\bar{x}$	$\frac{r^2\tan\alpha}{4h}$



Elliptic paraboloid	Volume	$\pi abc/2$
	$\bar{x}$	$2a/3$



4.3 Additional solutions for moments of inertia

Many engineering problems require that moments of inertia (I) be calculated. For example, the stresses in a beam can only be determined if the moment of inertia is known.

The moment of inertia of any area with respect to an axis in or perpendicular to the plane of the area is defined this way: the sum of the products obtained by multiplying each element of the area by the square of its distance from the axis.

4.4 Parallel axis theorem

4.5 *Plane geometric shapes* If the moment of inertia about a centroidal axis (i.e. an axis passing through the centroid) is known for a plane geometric shape, then the following equation describes the moment of inertia about any axis parallel to the centroidal axis:

$$I' = I_{cc} + AL^2$$

where I' = unknown moment of inertia
I_{cc} = centroidal moment of inertia
A = area of shape
L = distance of new axis from centroidal axis

Remember, however, this formula applies only if one of the two parallel axes passes through the centroid.

4.6 *Solids* If the moment of inertia about a centroidal axis for a solid is known, then the following equation describes the moment of inertia about any axis parallel to the centroidal axis:

$$I' = I_{cc} + mL^2$$

where I' = unknown moment of inertia
I_{cc} = centroidal moment of inertia
L = distance of new axis from centroidal axis
m = mass of solid
= density (ρ) times the volume of the solid

4.7 Radius of gyration

The following formulas describe the radius of gyration:

$$I = Ak^2$$

where I = moment of inertia
A = area of the section
k = radius of gyration

and $I = mk^2$

where m = mass of the solid

The radius of gyration represents the distance from the axis to the point at which all the area or mass could be concentrated to give an equal moment of inertia.

4.8 Polar moment of inertia

The polar moment of inertia (J) refers to the moment of inertia of an area with respect to a line perpendicular to the plane of the area. The following equation defines the polar moment of inertia, with respect to the z axis, of an area in the xy plane:

$$J_z = I_y + I_x$$

Hence the polar moment of inertia of any area with respect to any axis equals the sum of the moments of inertia of the area. Measure the moments of inertia with respect to the rectangular axes that intersect on the given polar axis in the plane of the area.

4.9 Moment of inertia of composite areas and volumes

When a composite area can be divided into geometric elements, such as rectangles or triangles, for which the moments of inertia are known, the moment of inertia for the composite area is the sum of the moments of inertia for the separate elements. However, these separate element moments of inertia must all be found with respect to the same axis.

Similarly, if the moments of inertia of the component parts of a solid are known with respect to the same axis, they can be added to give the total moment of inertia for the whole solid.

4.10 Centroids of composite areas

To find the distance from an axis to the centroid of a composite area, use this equation:

$$A\bar{y} = \Sigma a y$$

where A = area of composite area
$\bar{y}$ = distance from axis to centroid of composite area
a = area of component area
y = distance from axis to centroid of component area

4.11 Radian measurement

Radian measurement often makes physical measurement easier than using rectangular coordinates. A radian is an angle which, when placed with its vertex at the centre of a circle, intersects an arc equal in length to the radius.

If an angle of radian measure intercepts an arc, then, from the definition of circular measurement

$$s = r\alpha$$

where s = length of arc
r = radius
α = angle measured in radians

That is, the length of the circular arc intersected by an angle at the centre is equal to the radius times the radian measure of the angle.

The radian measure of any angle in degrees may be found from this relationship:

$$360° = 2\pi \text{ radians}$$

5 PSYCHROMETRICS

Psychrometrics is the study of the relationships that define the physical and thermal properties of mixtures of dry air and water vapor.

The psychrometric charts presented in Figs. 4–10 provide for dry-bulb temperatures of −40°C to +200°C at sea level and for dry-bulb temperatures 0°C to 50°C at three elevations (750 m, 1500 m, and 2250 m) above sea level.

The American Society of Agricultural Engineers publishes standards on psychrometric data that provide equations to enable the calculation of all psychrometric data if any two independent psychrometric properties of a mixture of air and water are known in addition to the atmospheric pressure. Often computers aid in analyzing psychrometric data.

5.1 Definitions

Terms that commonly appear in discussions of psychrometrics include:

- dry-bulb temperature
- wet-bulb temperature

- enthalpy
- relative humidity

5.2 *Dry-bulb temperature* This term refers to the temperature of the mixture of dry air and water vapor as measured with a clean, dry thermometer.

5.3 *Wet-bulb temperature* This term refers to the temperature of the mixture of dry air and water vapor, measured with a clean, wet thermometer as it moves rapidly through the air stream.

5.4 *Enthalpy* Enthalpy is a measure of the amount of thermal energy contained in a mixture of dry air and water vapor.

5.5 *Relative humidity* The relative humidity is the ratio of the partial pressure of the water vapor in the air to the partial pressure of water vapor in saturated air at the same temperature. Relative humidity is generally expressed as a percentage fraction.

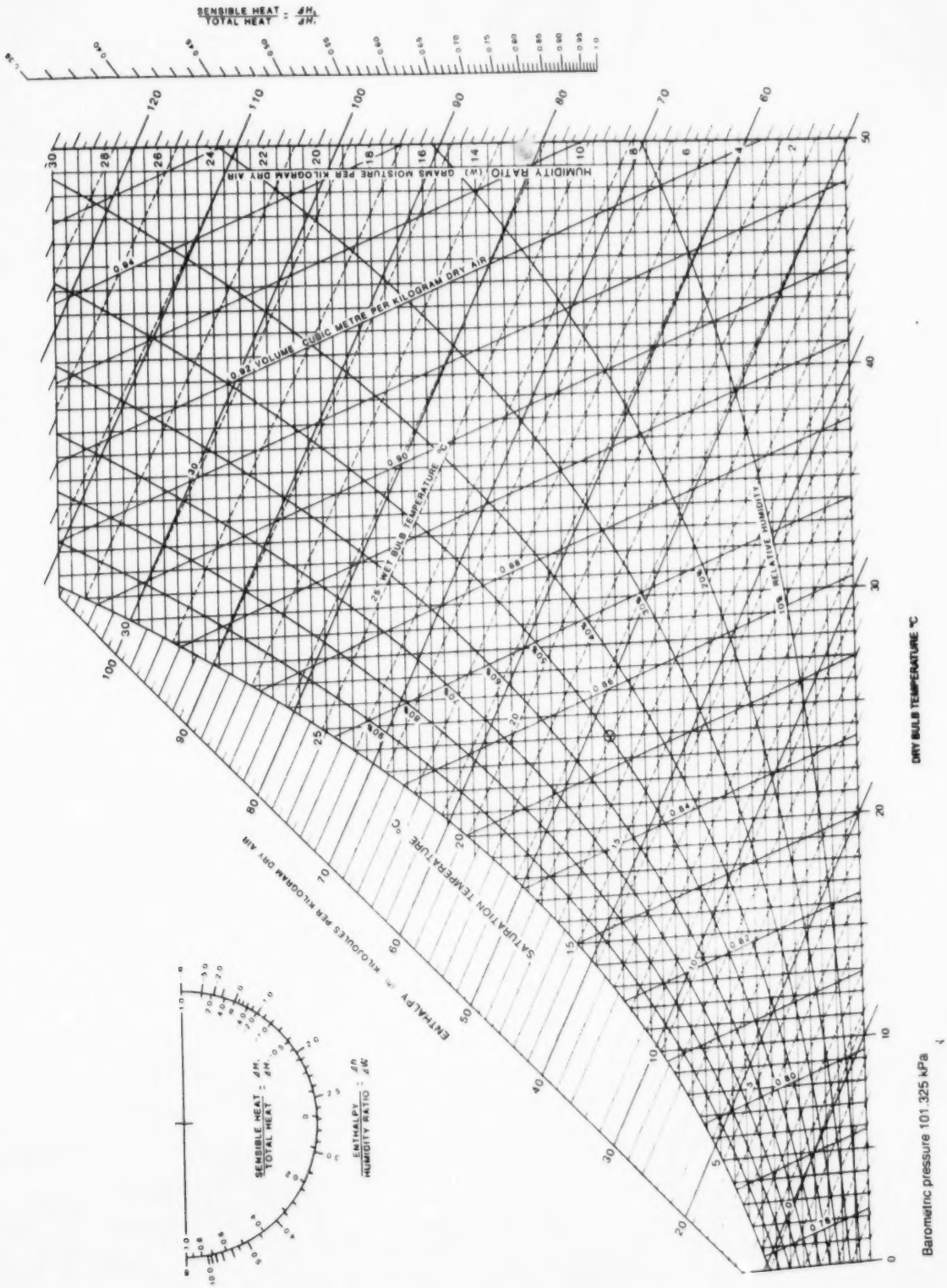

SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
WET BULB TEMPERATURE °C
RELATIVE HUMIDITY
SATURATION TEMPERATURE °C
ENTHALPY kILOJOULES PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
Barometric pressure 101.325 kPa
SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW

Fig. 4. Psychrometric chart: normal temperature, sea level.

Source: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.

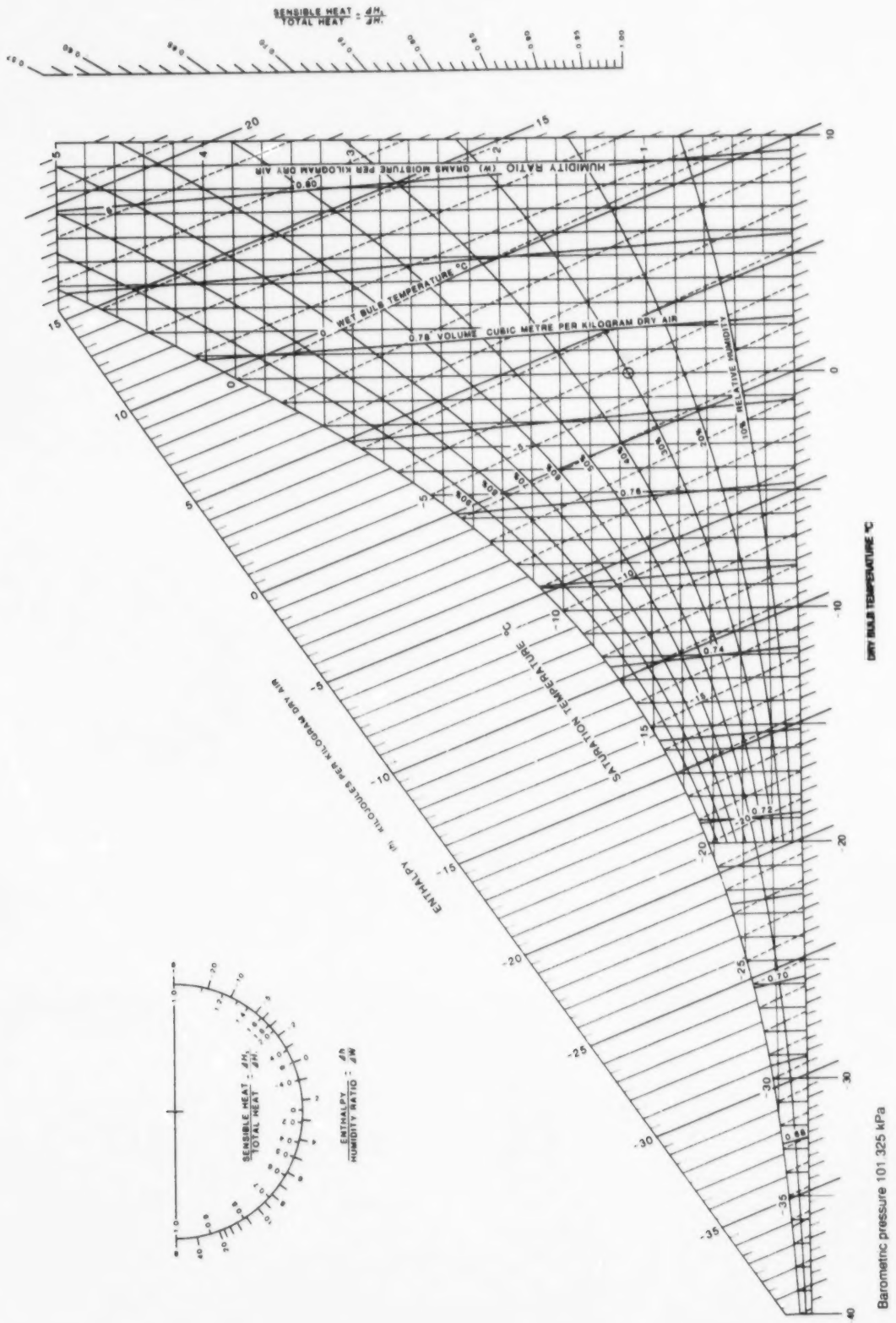

SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
HUMIDITY RATIO (W) GRAMS MOISTURE PER KILOGRAM DRY AIR
WET BULB TEMPERATURE °C
0.78 VOLUME CUBIC METRE PER KILOGRAM DRY AIR
% RELATIVE HUMIDITY
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
DRY BULB TEMPERATURE °C
Barometric pressure 101 325 kPa
SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW

Fig. 5. Psychrometric chart: low temperature, sea level.

Source: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.

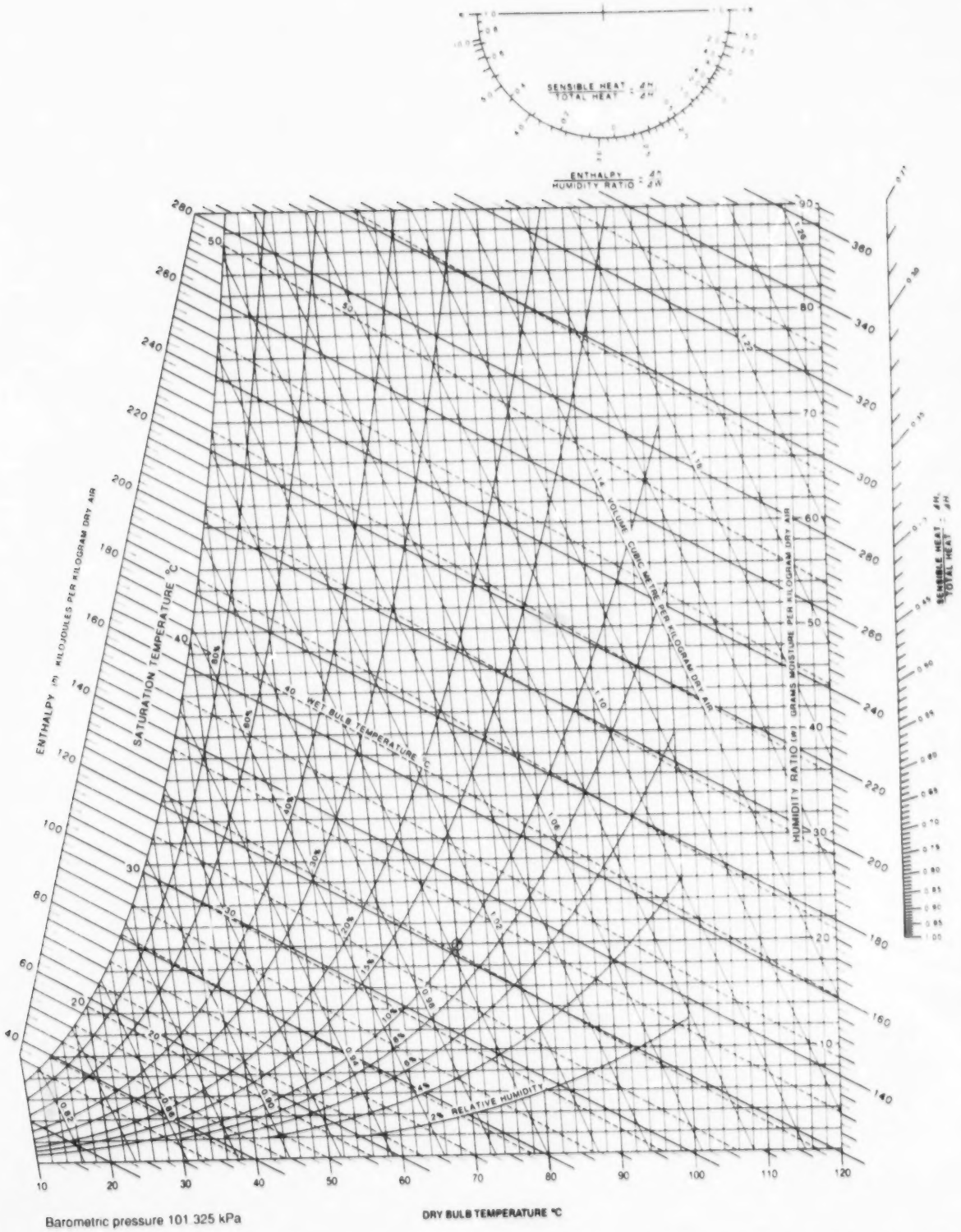

SENSIBLE HEAT / TOTAL HEAT = Δh / Δh
ENTHALPY / HUMIDITY RATIO = Δh / Δw
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO (w) GRAMS MOISTURE PER KILOGRAM DRY AIR
RELATIVE HUMIDITY
SENSIBLE HEAT / TOTAL HEAT
DRY BULB TEMPERATURE °C
Barometric pressure 101 325 kPa

Fig. 6. Psychrometric chart: high temperature, sea level.

Source: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.

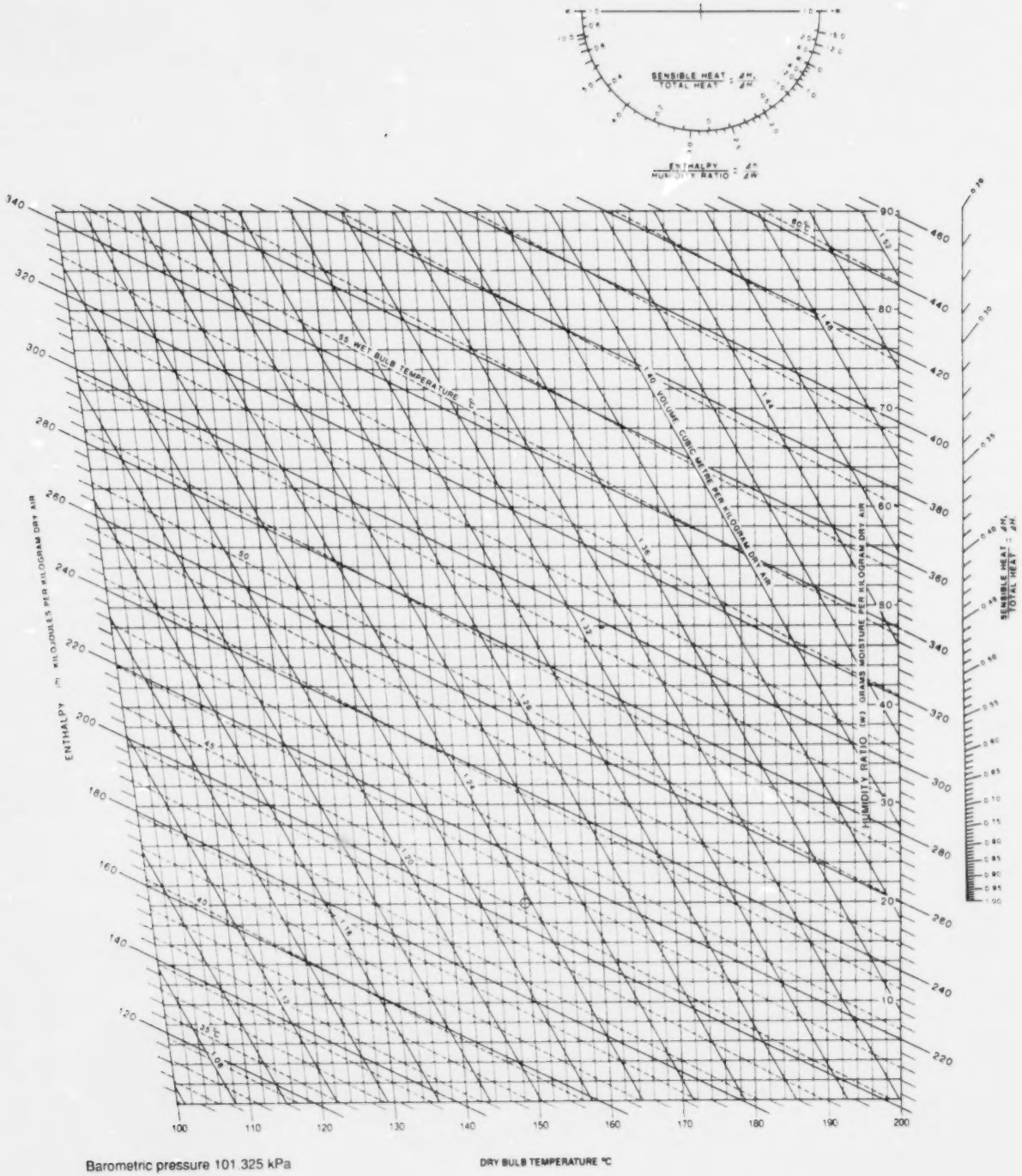

SENSIBLE HEAT / TOTAL HEAT = Δh/Δh
ENTHALPY / HUMIDITY RATIO = Δh/Δw
55 WET BULB TEMPERATURE °C
140 VOLUME CUBIC METRE PER KILOGRAM DRY AIR
ENTHALPY KILOJOULES PER KILOGRAM DRY AIR
HUMIDITY RATIO (w) GRAMS MOISTURE PER KILOGRAM DRY AIR
SENSIBLE HEAT / TOTAL HEAT = Δh/Δh
DRY BULB TEMPERATURE °C
Barometric pressure 101.325 kPa

Fig. 7. Psychrometric chart: very-high temperature, sea level.

Source: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.

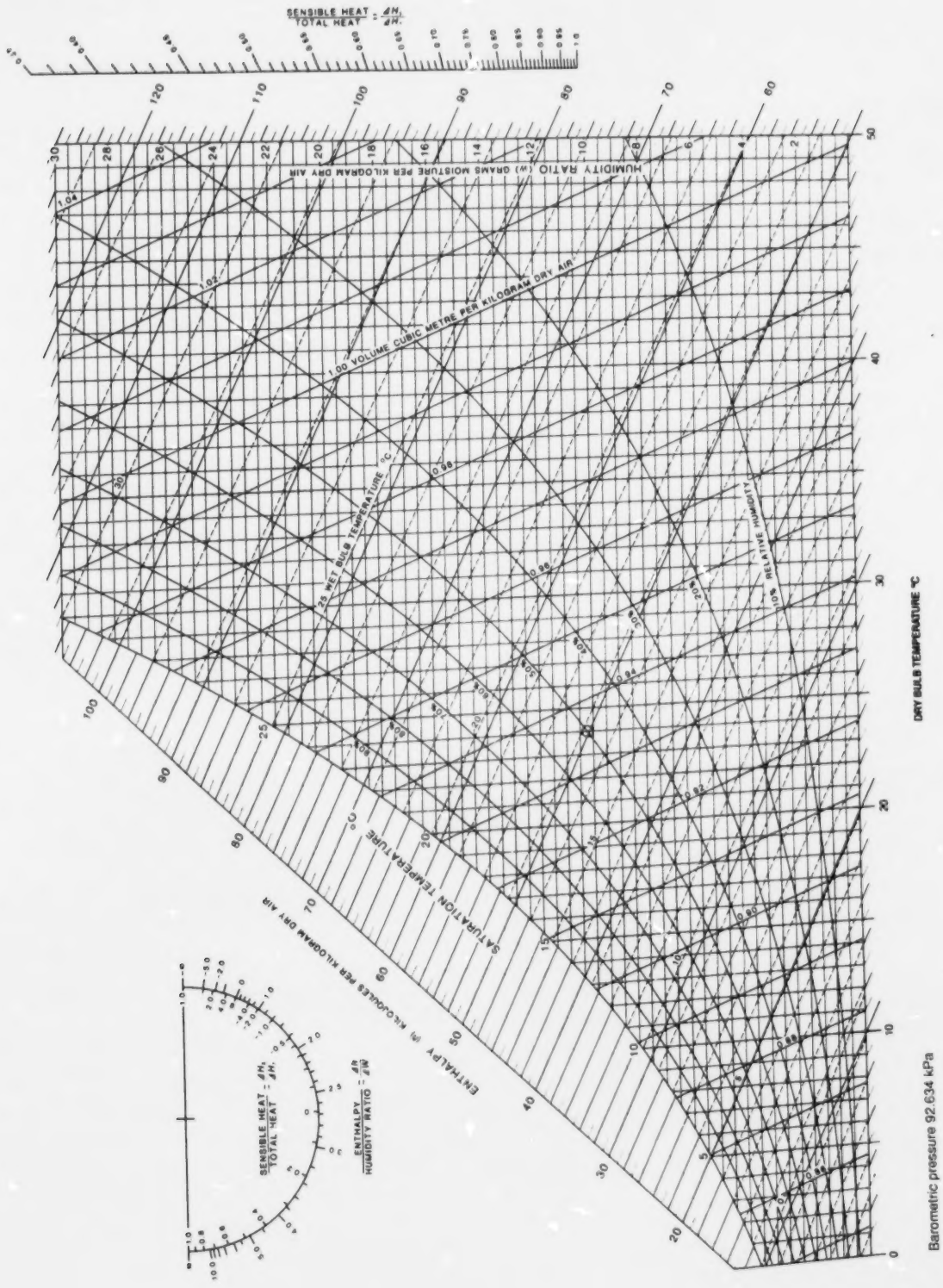

SENSIBLE HEAT / TOTAL HEAT = ΔH_s / ΔH
HUMIDITY RATIO (w) GRAMS MOISTURE PER KILOGRAM DRY AIR
1.00 VOLUME, CUBIC METRE PER KILOGRAM DRY AIR
WET BULB TEMPERATURE °C
RELATIVE HUMIDITY
SATURATION TEMPERATURE
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
Barometric pressure 92.634 kPa
SENSIBLE HEAT / TOTAL HEAT = ΔH_s / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / Δw

Fig. 8. Psychrometric chart: normal temperature, elevation 750 m.

Source: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.

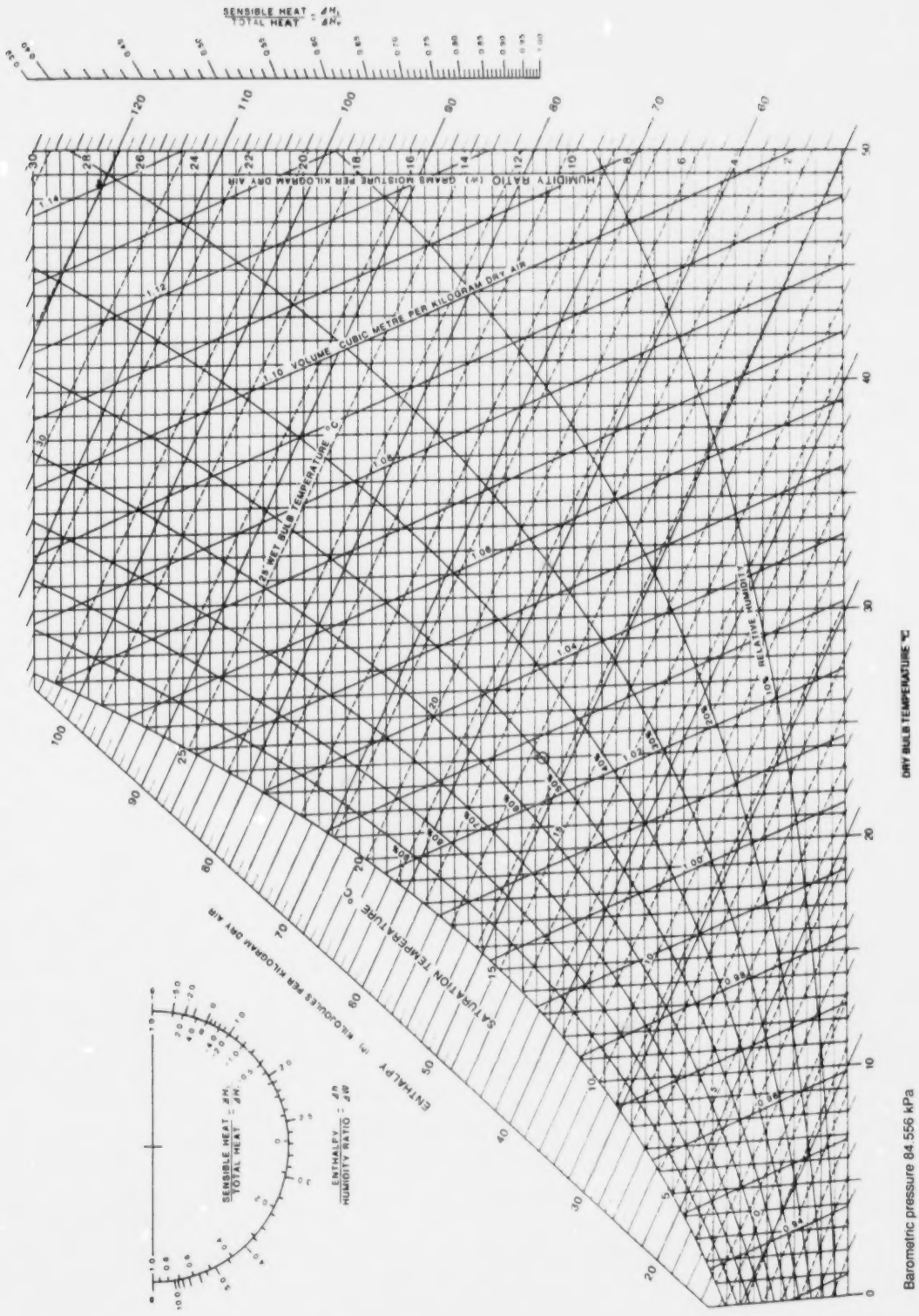

SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
HUMIDITY RATIO (w) GRAMS MOISTURE PER KILOGRAM DRY AIR
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
WET BULB TEMPERATURE °C
RELATIVE HUMIDITY %
SATURATION TEMPERATURE °C
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
DRY BULB TEMPERATURE °C
SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / Δw
Barometric pressure 84 556 kPa

Fig. 9. Psychrometric chart: normal temperature, elevation 1500 m.

***Source:* American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.**

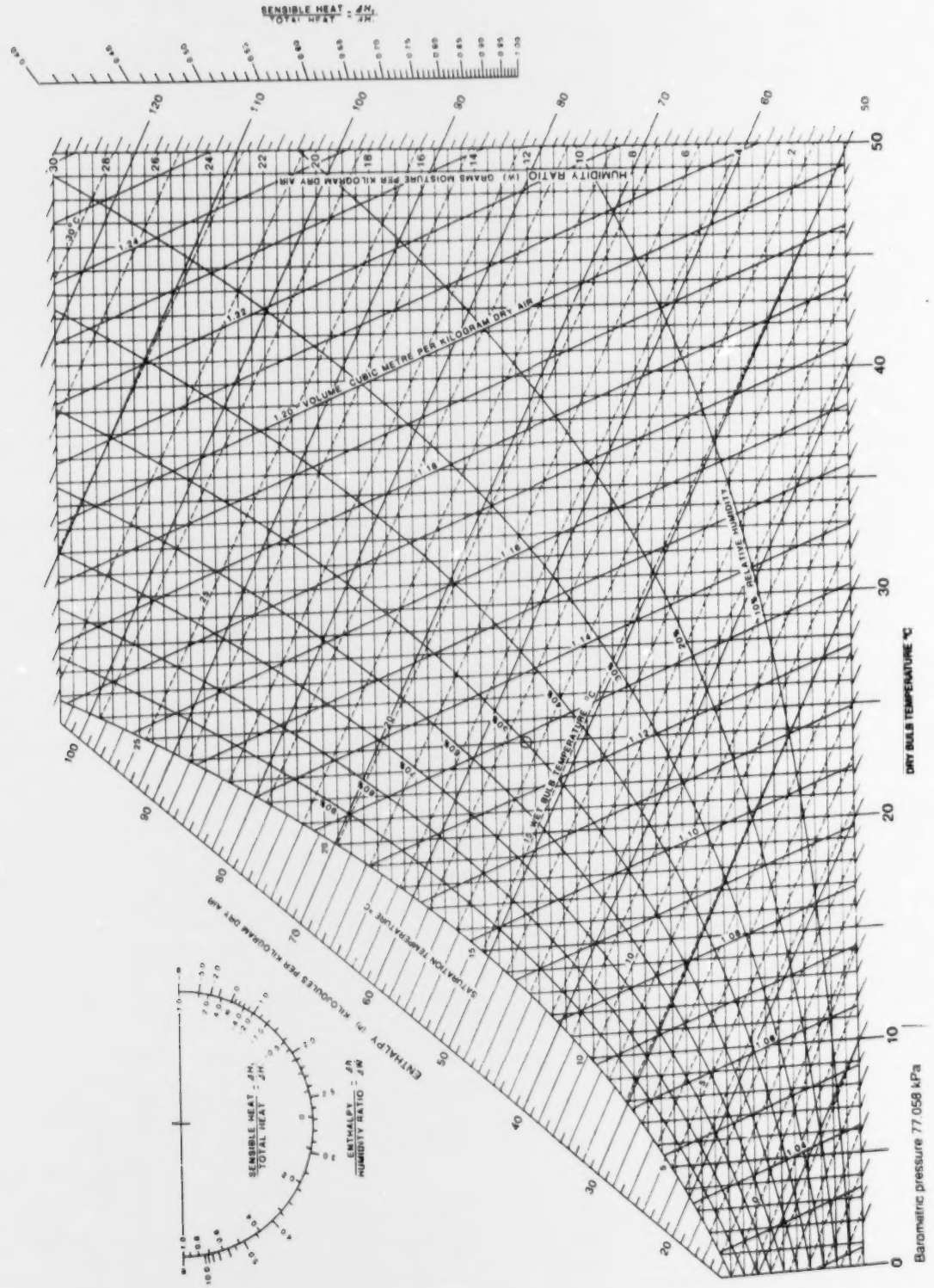

SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
HUMIDITY RATIO (M) GRAMS MOISTURE PER KILOGRAM DRY AIR
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
RELATIVE HUMIDITY
WET BULB TEMPERATURE °C
DRY BULB TEMPERATURE °C
SATURATION TEMPERATURE °C
ENTHALPY (h) KILOJOULES PER KILOGRAM DRY AIR
SENSIBLE HEAT / TOTAL HEAT = ΔH / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔM
Barometric pressure 77.058 kPa

Fig. 10. Psychrometric chart: normal temperature, elevation 2250 m.

Source: American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc. copyright 1982.

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INDEX

This composite index comprises key words and phrases to guide you through the seven volumes of *Handling Agricultural Materials*. The first number for each entry, followed by a slash, indicates the volume number in which the entry is found:

1 *Air and Pneumatic Conveyors*
2 *Screw and Bucket Conveyors*
3 *Liquid Conveyors*
4 *Electrical Controls and Instrumentation*
5 *Size Reduction and Mixing*
6 *Storage and Conditioning of Grain and Forage*
7 *Engineering Data*

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